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THIRD QUARTERLY PROGRESS REPORT
APRIL 1 - JUNE 30, 1981

DEVELOPMENT OF ADVANCED CZOCHRALSKI GROWTH PROCESS TO PRODUCE LOW COST 150 KG SILICON INGOTS FROM A SINGLE CRUCIBLE FOR TECHNOLOGY READINESS

PROGRAM MANAGER: R. L. LANE

KAYEX CORPORATION
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ROCHESTER, NEW YORK 14624

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CONTENTS

I INTRODUCTION

This program for "Advanced Czochralski Growth Process to Produce Low-Cost 150 kg Silicon Ingots from a Single Crucible for Technology Readiness" has several goals:

A. Provide a modified CG2000 crystal grower capable of pulling a minimum of five crystals, each of approximately 30 kg in weight, 150 mm diameter from a single crucible with periodic melt-replenishment.

B. Crystals to have: resistivity of 1 to 3 ohm-cm, p-type; dislocation density below 10^4 per cm^2; orientation (100); after growth yield of greater than 90%.

C. Growth throughput of greater than 2.5 kg per hour of machine operation using a radiation shield.

D. Prototype equipment suitable for use as a production facility.

E. The overall cost goal is $.70 (1980 $) per peak watt by 1986.

To accomplish these goals, the modified CG2000 grower and development program includes:

A. Increased automation with a microprocessor based control system which reduces operator attention and avoids operator errors.

B. Sensors development which, during the program, will increase the capability of the automatic controls system.

C. Process development which will: define the process control variables for accelerated growth rate using a radiation shield; analyze variations in the effects of silicon feed material and meltback rate of greater than 25 kg per hour; analyze the effects of these changes on the economic model; investigate and evaluate the effects of process variations on the "quality" of silicon produced by performing purity analysis of the silicon, solar cell fabrication/analysis, and furnace atmosphere analysis.

D. Provide technology transfer of the developed systems.

To accomplish the above goals, the program has been divided into five general categories:

A. Construction and Test - to provide a modified CG2000 grower for process development and sensor/automated controls integration.

B. Process Development - for accelerated growth, accelerated recharge and yield/cost improvement.

C. Controls and Automation - for sensor development and microprocessor control integration to the Mod CG2000.

D. Analytical Study - for purity analyses and solar cell fabrication.

E. Documentation - for reporting, economic analysis, and process specification.

During May, the program was redirected and extended to March, 1981. A hold on all equipment purchases was implemented and the Process Development effort scaled back and rescheduled for a later start date. Similarly, the Controls and Automation task and Analytical Study were also scheduled for scale-down. See Program Plan, Figure 1. The goals of the program remain the same.

II SUMMARY

The program was extended from October 31, 1981 to March 31, 1982 with the same goals and budget.

The process development continued, with a total of nine crystal growth runs. One of these was a 150 kg run of 5 crystals of approximately 30 kg each. Several machine and process problems were corrected and the 150 kg run was as successful as previous long runs on CG2000 RC's. The accelerated recharge and growth will be attempted when the development program resumes at full capacity in FY '82.

The automation controls (Automatic Grower Logic Computer System) were integrated to the seed dip temperature, shoulder, and diameter sensors on the CG2000 RC development grower. Test growths included four crystals, which were grown by the computer/sensor system from seed dip through tail-off. This system will be integrated on the Mod CG2000 grower during the next quarter.

The analytical task included the completion and preliminary testing of the gas chromatograph portion of the Furnace Atmosphere Analysis system. The system can detect CO concentrations and will be expanded to oxygen and water analysis in FY '82.

A revised economic analysis, using the desired throughput rate of 2.5 kg per hour at 6" diameter, shows a 4.4% cost advantage and a 24% reduction in pull average speed for three, 50 kg crystals over five, 30 kg crystals.

The revised program plan is on schedule and is expected to remain close to the cost and schedule projections during the next quarter.

III PROGRESS

A. Construction and Test

This task was completed in March. All design changes, maintenance and/or problems with the equipment are reported in the other sections.

B. Process Development

This is a new design crystal grower (Mod CG2000) including hot zones, designs, and crucible sizes never used in previous growers.

The objective of the first several growth runs is to debug the machine itself and provide information on the performance of the grower to the process parameters. The results of these test runs help dictate the corrective actions necessary before starting the extended runs with multiple recharges.

The first trial run was reported in the January - March Quarterly report and resulted in several problems being corrected.

During April, a total of four trial runs were performed (see Table 1).

These runs resulted in the discovery of the following problems/corrective actions:

1. Water and air leaks/extensive chamber leak checking, welded leaks, and new "O" ring seals installed. These leaks were felt to be the cause of the excessive oxide smoke, oxide deposits, and O-D structure loss.

2. Machine Hardware:

   a. Growth loop reversal/corrected

   b. Melt vibration/crucible rotation bearings replaced

   c. The PCC (150 KW) power supply was removed for testing and replaced with Robicon (125 KW). The 150 KW unit will be replaced in the Mod CG2000 for evaluation after other problems with the grower are resolved.

   d. The aluminum oxide spill tray was suspected as a source of contaminating water/air. One has been reprocessed by the vendor

and will be tested in later runs. Additional graphite felt was used as a baseplate insulator and protector.

The results of these four runs indicate that further chamber leak checks are needed. It is also necessary to conduct further crystal growth runs using 14" crucibles to demonstrate improved cleanliness and zero-dislocation growth capability.

During May, two process test and machine debug runs were performed: runs No. 6 and No. 7 (see Table 2).

Prior to run number 6 being made, repair and maintenance were performed on the crystal grower as follows:

1. The 125 KW Robicon power supply was replaced with the 150 KW P.C.C.
2. A new crucible support insert was fitted.
3. The total hot zone was baked out for approximately 12 hours. A total of 25 kg of recycle silicon was utilized for the run in a 14 inch diameter crucible.

The purpose of this growth run was to check that the furnace environment was cleaner and, as a consequence, demonstrate the ability to produce a zero dislocation crystal. During melt down, the furnace and the crucible remained clean and smoke-free. The melt temperature and seed dip sequence was completed at an operating pressure of 10 torr. Periodic smoking of the melt was then observed, so the furnace operating pressure was raised to 30 torr. The neck and crown operation was performed at a pressure of 30 torr and the general observation was that significantly less smoke was visible at this stage than was observed during the preceding run (run No. 5).

Zero dislocation growth was achieved at the first attempt and was maintained throughout the run. The resultant crystal was significantly cleaner in appearance than any of the previous crystals grown.

All visible viewport weld areas were continuously monitored during the

growth cycle. No visible problems were noticed; even layers of oxide were deposited on all water-cooled weld areas.

As a result of this crystal growth run, it was felt that the furnace environment could be maintained at an operating pressure of 20 torr by more effectively distributing the argon flow around the furnace tank. Future use of a radiation shield system would achieve this when the accelerated growth program is implemented.

In order to improve the argon distribution factor and also reduce the operating pressure to 20 torr, a 19 inch diameter grafoil sleeve was placed between the furnace tank cover plate and the graphite upper ring. The furnace tank internal diameter is 27 inches. The total system was baked out prior to crystal growth run number 7.

During the meltdown sequence, no smoke was visible in the furnace, but a small amount was visible during temperature stabilization after meltdown. This small amount remained visible during the first 3 inches of crystal growth, but was a considerable improvement over any of the previous growth runs. Also, the crucible walls were considerably cleaner than previously, with only a light oxide coating being visible on the crucible walls.

The thermal profile within the grower was obviously changed as a result of inserting the grafoil sleeve. Various attempts were made at crown growth to evaluate the crucible start position. When the optimum position was determined, the growth run was continued. The resultant crystal was not zero dislocation.

The appearance of the crystal grown during run number 7 was as follows:

1. Crown totally free of oxide formation.

2. Oxide was restricted to a 7" band in the middle of the crystal.

See Table 2 for additional data.

Four crystal growth runs were made during June - runs Nos. 8, 9, 10, and 11 - one of which (No. 10) was a 150 kg run.

The main purpose of run No. 8 was to demonstrate zero-D crystal growth from the charged thermal configuration due to the use of a 19 inch diameter grafoil sleeve. In addition, the operation of the isolation valve and recharge hopper was checked out by hot filling about 10 kg into an initial melt of 25 kg.

Hot filling was successfully achieved in spite of some chunks lodging in the hopper. However, the isolation valve had a leakage problem which did allow some air into the furnace tank during the pull chamber purging operation. After meltdown and stabilization, four attempts were made to obtain dislocation free crystal using different crucible start positions each time. At the fourth attempt, the crystal was zero-D over the crown and continued so for 15.5 inches of body growth. The condition of the crucible and crystal was not as clean as in run No. 7, but a considerable improvement over earlier runs. Furnace pressure was maintained at 20 torr and argon flow was 60 scfh at an inlet pressure of 25 psi. The relevant process data for this run are presented in Table 2.

Growth run No. 9 was the first run made using an Ircon sensor for automatic diameter control. The run was set up to check out calibrations and fine tune the ADC loop for optimum performance. It was also decided to make this a 2-crystal run to practice the recharging procedure prior to making a 150 kg run. The argon purge sleeve was retained.

Two crystals were pulled, the first being all zero-D, but the second becoming dislocated after 2 inches body growth. Diameter control with the Ircon sensor was good, after an initial adjustment period. There were two problems associated with the recharging operation:

1. Silicon bridging in the hopper - This was due to large "flake-like"

silicon chunks present in the particular batch of polysilicon being used. The problem was overcome by switching to a smaller size range of polysilicon.

2. There was an air leak problem due to the isolation valve O-ring burning. The exact cause needs to be investigated, but the subsequent contamination of furnace atmosphere and crucible undoubtedly led to the loss of structure experience with the second crystal.

In the summary of data, Table 2, the pulled yield, zero-D yield, and throughput for multicrystal runs are all based on the total material pulled.

The object of run No. 10 was to pull five consecutive 30 kg crystals from the same crucible utilizing the recharge procedure. The run was made with the grafoil sleeve positioned on top of the heat pack, and retaining the Ircon for diameter control.

A total of 145.5 kg was pulled in 100 hours at a pulled yield of 95.2%. The first two crystals were approximately 90% and 65% zero-D respectively, but subsequent crystals did not retain structure in spite of repeated attempts to achieve it. Two main problems were encountered during the run:

1. Air leakage through the isolation valve - There was a tendency for the isolation valve O-ring to lift out of its seating during opening of the isolation valve. If it did not re-seat correctly, then an air leak would occur when the pull chamber was opened for crystal removal and hopper loading. It was also noted that the O-ring was getting hot in one particular region and starting to burn, which would indicate inadequate cooling.

   Any air leakage during the recharge operation would undoubtedly contribute to structure loss problems.

2. Corkscrewing - At a mean pull speed of 2.75 in/hr, all five crystals

grew in a slightly twisted fashion, a phenomenon usually referred to as 'corkscrewing'. The short term solution was to reduce pull speed which, of course, affects throughput. In the long term, the reason for corkscrewing, usually ascribed to thermal asymmetry, needs to be investigated.

Run No. 11 was an attempt to shed some light on the reason for structure loss during multiple-crystal growth runs. After run No. 10, the furnace was opened and very carefully unloaded. Care was taken not to disturb the oxide deposit on the furnace parts. A new crucible was placed in the hot zone and loaded with 35 kg of silicon. The object of the exercise was to determine the grower's capability to produce zero-D crystal with a new crucible and silicon, but no other preparation. In other words, it was a test of which is the more important factor causing structure loss - oxide build-up in the furnace, or crucible degradation.

Unfortunately, a crucible support failure occurred and the run had to be aborted.

Results

There were several accomplishments during this quarter:

1. Several hot zone and machine debug runs have resulted in a cleaner furnace environment, crucibles, and crystals. Hot zone modifications included a grafoil sleeve for more effective purge. This will be replaced with a cone in later runs.
2. The diameter control was changed to an Ircon sensor and Kayex electronics.
3. A 150 kg run was performed at an average pull rate of 2.3 inches per hour.

Plans

1. Check out machine alignment and hot zone to find cause of corkscrewing.

2. Prepare grower for growth runs using microprocessor control.

C. Controls and Automation

1. General

Activities in this area continued generally as outlined in the March Quarterly Report. Efforts centered on integrating the shoulder and diameter sensors with the Automatic Grower Logic (AGL)* computer system and testing the system on the CG2000 RC grower prior to integrated tests with the modified CG2000.

2. Shoulder Sensor

A critical step in crystal growth occurs at the transition from the relatively flat crown to growth of the cylindrical portion of the ingot. Performing this transition (referred to as the shoulder) requires that the seed lift rate be increased and heater temperature be decreased. These variations are performed based on information stored in the AGL process tables. A sensor has been implemented to automatically key the start of the shoulder in the AGL computer.

The shoulder sensor is a focused optical pyrometer aimed at the growth radius where the shoulder transition is to begin. The solid silicon of the ingot crown has a significantly higher emissivity than the liquid silicon of the melt. Although the crown is cooler than the melt, the higher emissivity results in an increased output from the optical pyrometer when the crown is in the pyrometer's field of view. The AGL computer then begins the process steps for shoulder growth when the pyrometer output exceeds a preset threshold.

Growth of the shoulder continues until the image of the meniscus

*Automatic Grower Logic is a proprietary development of the Kayex Corporation.

the crystal/melt interface is acquired by the separate diameter sensor described below.

3. Diameter Sensor

The diameter sensor is also a focused optical pyrometer. The output of this sensor is used as input to a PID control loop implemented in the AGL software. The output of the PID control is the Seed Lift Rate in the normal Automatic Diameter Control configuration. The output of the diameter sensor varies as the crystal diameter changes and the position of the bright meniscus moves relative to the field of view of the pyrometer.

4. Sensor Implementation

The diameter and shoulder sensors consist of silicon detector heads coupled by fiber optics to remote imaging lens assemblies. The imaging lenses are designed to give the sensors an effective field of view, that is, a circular spot 0.15 inches in diameter in the plane of the melt surface. The sensors are mounted on a micrometer-driven translation stage, which allows precise positioning of their respective fields of view along a radius of the crystal grower. This arrangement allows the sensors to be preset for the desired shoulder radius and ingot diameter.

The imaging lens and mount assembly, as implemented on the test grower, is shown in Figure 1.

5. Test Program

The above described configuration of sensors has been implemented on the CG2000 RC development grower assigned to the project for test purposes. Four crystals of four-inch diameter were grown from 12-kilogram charges. The previously reported automatic dip temperature setting technique and the shoulder and diameter sensors were used with the AGL computer system. Two of the crystals are shown in Figure 2. The crystals demonstrate the high degree of reproducibility achievable with the sensor and AGL computer configuration.

6. Mod CG2000 Controls

During this reporting period, the fabrication, mounting and alignment of melt temperature, body and shoulder sensors on the modified CG2000 grower have been completed. Integration of the sensors with the AGL computer system is scheduled for July. During that month, it is planned to perform integrated tests by growth of six-inch diameter material.

D. Analytical Study

The analytical task consists of three areas:

1. Purity Analyses of Silicon - The control of silicon purity will be achieved by chemical impurity analysis of selected samples from feedstock, grown ingots and residual melt.
2. Solar Cell Fabrication and Analysis - Selected ingot material from all 150 kg runs will be sliced into wafers and, along with several control samples, fabricated into solar cells. These cells will also be tested for solar efficiency.
3. Furnace Atmosphere Analysis - A gas chromatograph, oxygen analyzer, and hygrometer with an automatic sampling system will be used to monitor the oxygen, water, carbon monoxide and other possible impurities.

During this quarter, the work continued on the Furnace Atmosphere Analysis System.

The total system is a combination of three basic components used for detection and concentration measurements:

1. Gas Chromatograph - for CO and gases other than oxygen and water.
2. Oxygen Analyzer - for O_2.
3. Hygrometer - for water.

The three components require a sampling system, integrator, calibration and purge gases and total assembly on a moveable cart for mobility.

Because of the program stretch-out, the system has been constructed for accepting all three components, but only the gas chromatograph (manual operation) has been purchased. The remaining components are scheduled for FY '82.

In late May, the first attempts were made at calibration of the G.C. with calibration gas having 760 ppm CO in the air. This was done at atmospheric pressure, and showed the G.C. detector was capable of measuring CO by observing the peak height. A diluted sample (7.6 ppm) showed a corresponding lower peak height. These attempts also showed the second column (molecular sieve) was defective.

The second column was replaced and the system was interfaced to the Mod CG2000 for actual furnace atmosphere sampling.

The next attempt at debug and CO calibration was done at 20 torr input pressure to simulate the furnace sampling input pressure. A standard gas mixture of 2390 ppm of CO in agron was used, since this corresponds to the expected concentration of CO observed in previous work. The CO peak on the recorder occurred at about two minutes and fifteen seconds following injection of the CO gas into the column. However, a problem was observed when the CO peak height varied inversely as the hold (equilibration) time. In this operation, the peak height should be independent of the hold time. It is suspected that a leak in the rotary sampling valve or lines is the cause of the problem.

During the next reporting period, the G.C. system will continue to be debugged and used for sampling actual CO concentrations in the furnace atmosphere.

E. Documentation - Economic Analysis

A revised CZ Add-On Cost analysis was completed and is included in Table 3.

The cost is projected using a desired throughput rate of 2.5 kg per hour at 6" diameter for 150 kg total pulled weight. The three cases analyzed are:

Case		CZ Add-On	
		$/Hr[2]	$/Peak Watt
1	Pulling 5 crystals, each 30 kg	21.62	0.1525
2	Pulling 4 crystals, each 37.5 kg	21.13	0.1490
3	Pulling 3 crystals, each 50 kg	20.66	0.1457

These analyses are based on mid-1981 process expectation and equipment cost projections, but are shown in 1980 dollars.

There is a 4.4% cost advantage and a 24% reduction in average pull rate for the three, 50 kg crystals over five, 30 kg crystals.

IV PROGRAM PLAN

The extension of the program has resulted in a revision No. 2 to the plan, which is updated in Figure 3.

V COST AND DIRECT LABOR DATA

The total incurred cost and direct labor graphs have been revised and updated. They are shown in Figures 4 and 5, respectively.

	Previous Total	Current Month	Total To Date
Costs	$ 498,243	$ 8,060	$ 506,483
Man Hours	4,262.6	413.0	4,675.6

Row No.	Date	Charge weight - recycle silicon (kg)	Pulled weight (kg)	Melt down time (hrs)	Crucible size (in)	Hot zone size (in)	Power supply used	Crown/xtal attempts for "O-D"	Smoke-in furnace	Oxide coating on xtal/crown	Crucible wall freeze/dirty with oxide	Taper of xtal	Water/air leaks	Crucible Devitrification - excessive	Comments
2	4/2/81	31.8	23	2	15	15	PCC 150 kW	2	Excessive	Yes, heavy	Yes, freeze caused xtal size to exceed auto-control limit	Yes, 5.7" to 6.2" over 8 inch length	Yes, water near argon port	Yes	2nd attempt for O-D resulted in 4" xtal; growth loop reversed, caused structure loss; water leak in throat.
3	4/9/81	30	20.7	3	14	15	Robicon 125 kW	2	Excessive	Yes, heavy	Yes, freeze; also heavy oxide coating	Yes	Suspected	Yes	1st attempt for O-D, 3" xtal; 2nd attempt, lost on crown. Power readout not available due to Robicon supply; water leak suspected; air leak found with later testing.
4	4/21/81	25	19	3	14	15	Robicon 125 kW	1	Moderate	Yes, but moderate	No, clean and freeze-free	No	No	Yes	No - spill tray; crucible melt vibration caused structure loss at 8 kg (8"); control diameter okay previous to melt vibration. Crucible shaft bearings replaced after run.
5	4/28/81	25	18	3	14	15	Robicon 125 kW	1	Excessive	Yes, heavy	Yes - wall freeze	No	Suspected site observed		No - spill tray - 1st attempt was O-D, until 5" of xtal; Wall freeze occurred.

PROCESS TEST RUNS - NOS. 2-5

TABLE 2
GROWTH RUN DATA

	ITEM	UNITS	PROCESS DATA											
1	Run #	-	6	7	8		9	9		10	10	10	10	10
2	Date	-	5/5/81	5/12/81	6/10/81		6/16/81	6/17/81		6/22/81	6/22/81	6/23/81	6/24/81	6/25/81
3	Crystal #	-	1	1	1		1	2		1	2	3	4	5
4	Charge - Cold Fill	kg	25	25	25		28.5	-		35	-	-	-	-
5	- Hot Fill	kg	-	-	10.25		6.5	25		-	30.1	30.1	28.9	28.7
6	Crucible Diameter	in	14	14	15		15	15		15	15	15	15	15
7	Silicon-New/Recycle	-	Recycle	Recycle	Recycle		Recycle	New		New	New	New	New	New
8	Seed	-	1-0-0	1-0-0	1-0-0		1-0-0	1-0-0		1-0-0	1-0-0	1-0-0	1-1-1	1-1-1
9														
10	Meltdown Power	kw	110	110	106		83	106		88	110	110	110	100
11	Total Meltdown Time	hr	2	2	2.25		4.5	2.5		3.0	2.4	2.1	2.16	2.16
12	Start Neck Power	kw	78	77	74		70	71		72	72	72	73	70
13	15" Body Power	kw	81	82	88		74	75		74	75	75	74	73
14														
15	Crystal Diameter	in	5.4	5.5	5.5		5.85	5.9		5.88	5.95	6.1	6.2	6.2
16	Pulled Weight	kg	20.0*	17.5	32.5		25.3	24.7		30.4	30.6	29.1	28.4	27.0
17	Residual Melt	kg	5.0	7.5	2.75		9.7	10.0		4.6	4.1	5.1	5.6	7.3
18	Zero-D - Length	in	21	0	15.5		24.6	2.0		25.5	18.5	0	0	0
19	- Weight	kg	20	0	14.0		25.3	2.0		26.2	19.6	0	0	0
20	Body Growth Time	hr	11	9.2	15		9.5	8.0		11.37	12	12.25	11.25	11
21	Cycle Time (Power	hr	15	15	25.25		→	31.5		→	→	→	→	100
22	On-Power Off)													
23														
24	Pulled Yield	%	80*	70	92.2		→	83.3		→	→	→	→	95.2
25	Avg. Pull Speed	in/hr	2.1	2.0	2.3		2.53	3.0		2.48	2.46	2.25	2.26	2.13
26	Zero-D Yield	%	80	0	43.1		→	54.6		→	→	→	→	31.5
27	Machine Throughput	kg/hr	1.33	1.17	1.29		→	1.59		→	→	→	→	1.46
28		*Run was terminated to coincide with the end of a shift.												

TABLE 3

ECONOMIC ANALYSIS
CZ ADD-ON COST PROJECTIONS BASED ON
GROWER THROUGHPUT GOAL OF 2.5 KG/HR

CONDITIONS	1	2	3
Crucible Diameter (in)	16	16	16
Crystal Diameter (in)	6	6	6
Total Poly Melted (kg)	158	158	158
Total Crystal Pulled (kg)	150	150	150
Avg. Straight Growth Rate (in/hr)	4.05	3.5	3.1
Pulled Yield (%)	94.9	94.9	94.9
Yield After CG (% of Melt)	83.5	85.4	87.3
Individual Crystal Wt. (kg)	30	37.5	50
No. Crystals/Crucible	5	4	3
Cycle Time (hr)	60	60	60

PROCESS CYCLE TIMES)

OPERATION	TIME (MINS)		
1. Preparation			
Load Polysilicon	15	20	25
Close Furnace	5	5	5
Pump Down	15	15	15
Melt Down	105	115	135
Subtotal	140	155	180
2. Growth Cycle (Initial)			
Lower Seed	*	*	*
Stablilize Temp.	30	30	30
Neck Growth	20	20	20
Crown Growth	55	55	55
Straight Growth	347	515	795
Taper End	60	60	60
Subtotal	512	680	960
3. Recharge/Growth Cycle	(X4)	(X3)	(X2)
Cool Crystal	30	30	30
Remove Crystal	10	10	10
Load Hopper, Vac Down (X2)	60	60	60
Lower Hopper (X2)	10	10	10
Dump and Melt	80	85	90
Lower Seed	*	*	*
Stabilize Temp.	30	30	30
Neck Growth	20	20	20
Crown Growth	55	55	55
Straight Growth	347	515	795
Taper End	60	60	60
Subtotal	702	875	1160
	(X4) 2808	(X3) 2625	(X2) 2320

TABLE 3 (CONT'D)

	1	2	3
4. Shut Down Cycle			
Cool Furnace	80	80	80
Remove Crystal	**	**	**
Clean, Set Up	60	60	60
Subtotal	140	140	140
Total Cycle Time (Mins)	3600	3600	3600

*Completed during Melt Stabilization Time
**Completed during Furnace Cooling Time

Growth Rate Calculation

Grow Diameter (in)	6.2	6.2	6.2
Straight Crystal Wt (kg)	27	34.5	47
Straight Growth Time (hr)	5.78	8.58	13.25
Avg. Growth Rate (kg/hr)	4.67	4.02	3.55
Wt per Unit Length (kg/in)	1.153	1.153	1.153
Avg. Pull Rate (in/hr)	4.05	3.49	3.08

SAMICS/IPEG INPUT DATA AND COST CALCULATION

INPUT DATA ($ 1980)	1	1	3
1. Capital Equipment Cost [EQPT]	$ 247,560	$ 247,560	$ 247,560
2. Floor Space [SQFT]	120	120	120
3. Annual Direct Salaries			
Prod. Operator (0.65 man @$13160/yr)	8,554	8,554	8,554
Elect. Tech (0.3 man @$16940/yr)	5,082	5,082	5,082
Inspector (0.1 man @$11550/yr)	1,155	1,155	1,155
Total [DLAB]	$ 14,791	$ 14,791	$ 14,791
4. Direct Materials Usage based on Machine Utilization of 85% = 124 cycles/yr			
Crucibles 16 x 12 @$345	42,780	42,780	42,780
Seeds ($20 each)	2,480	2,480	2,480
Dopant ($25/cycle)	3,100	3,100	3,100
Argon (60 ft^3/hr at $0.05/$ft^3$)	22,320	22,320	22,320
Graphite (4 sets 16" graphite parts per yr @$8,889/set)	35,556	35,556	35,556
Materials Total [MATS]	$ 106,236	$ 106,236	$ 106,236

TABLE 3 (CONT'D)

		1		2		3
5. Utilities						
Electricity @$0.04/kw hr						
Meltdown @100 kw		3,513		3,058		2,604
Avg. Grow @75 kw		18,600		18,910		19,220
Water @0.7¢/ft^3		12,106		12,106		12,106
30 gpm for 97% cycle						
Utilities Total [UTIL]	$	34,219	$	34,074	$	33,930

IPEG Price		5 x 30 kg crystals		4 x 37.5 kg crystals		3 x 50 kg crystals
C1 EQPT x $0.57/yr = $EQPT		141,109		141,109		141,109
C2 SQFT x $109/yr = $SQFT		13,080		13,080		13,080
C3 DLAB x $2.1/yr = $DLAB		31,061		31,061		31,061
C4 MATS x $1.2/yr = $MATS		127,483		127,483		127,483
C5 UTIL x $1.2/yr = $UTIL		41,063		40,889		40,716
Total Annual Cost	$	353,796	$	353,622	$	353,449
Quan (total Charged x Yield after CZ)(kg)		16,360		16,732		17,104
Add-On Cost($/kg)		21.62		21.13		20.66
Add-On Cost(¢/Peak Watt) (Assumes 1 kg = 1 M^2)		15.25		14.90		14.57

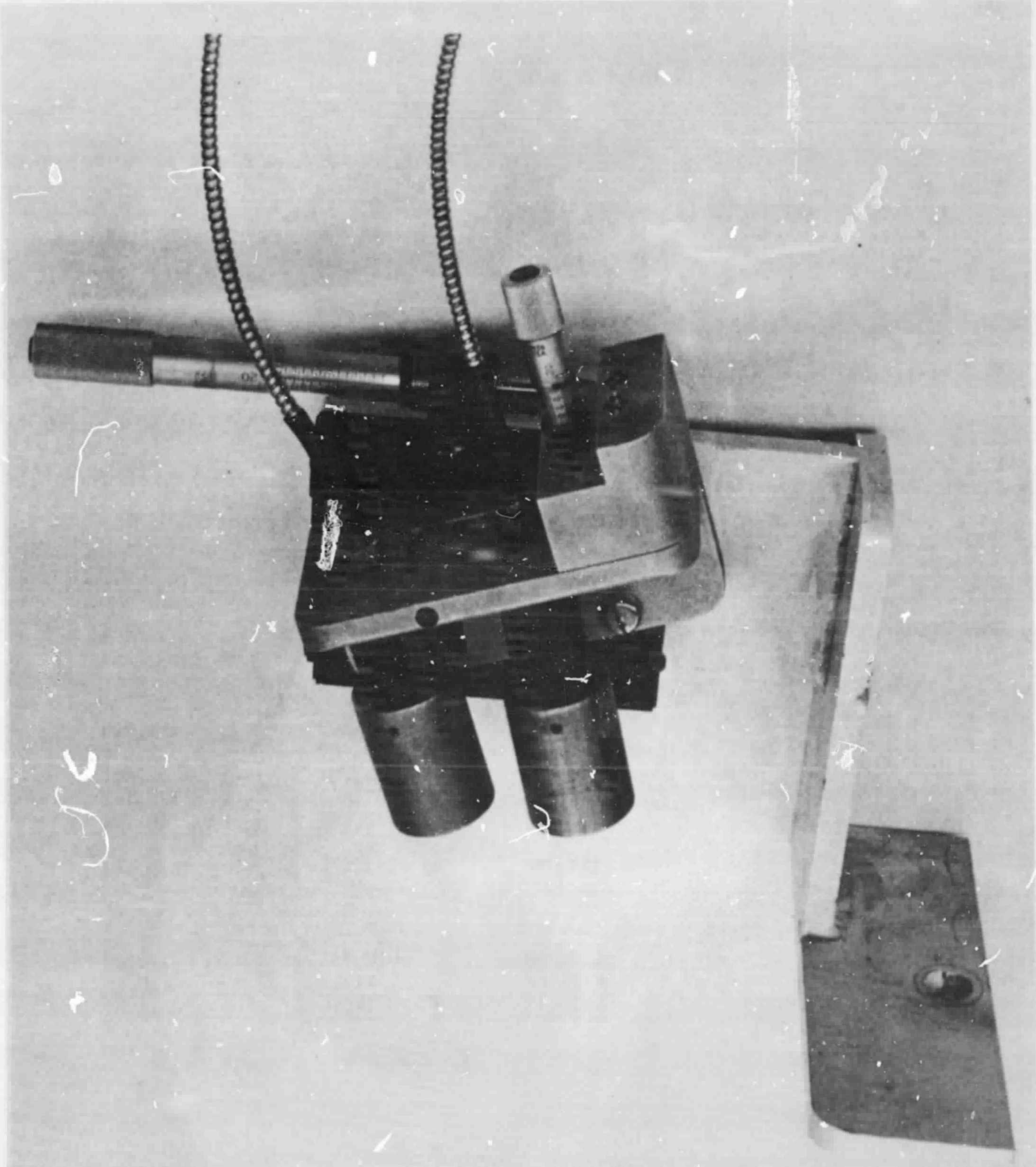

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FIGURE 1
DIAMETER AND SHOULDER SENSOR LENS AND MOUNT

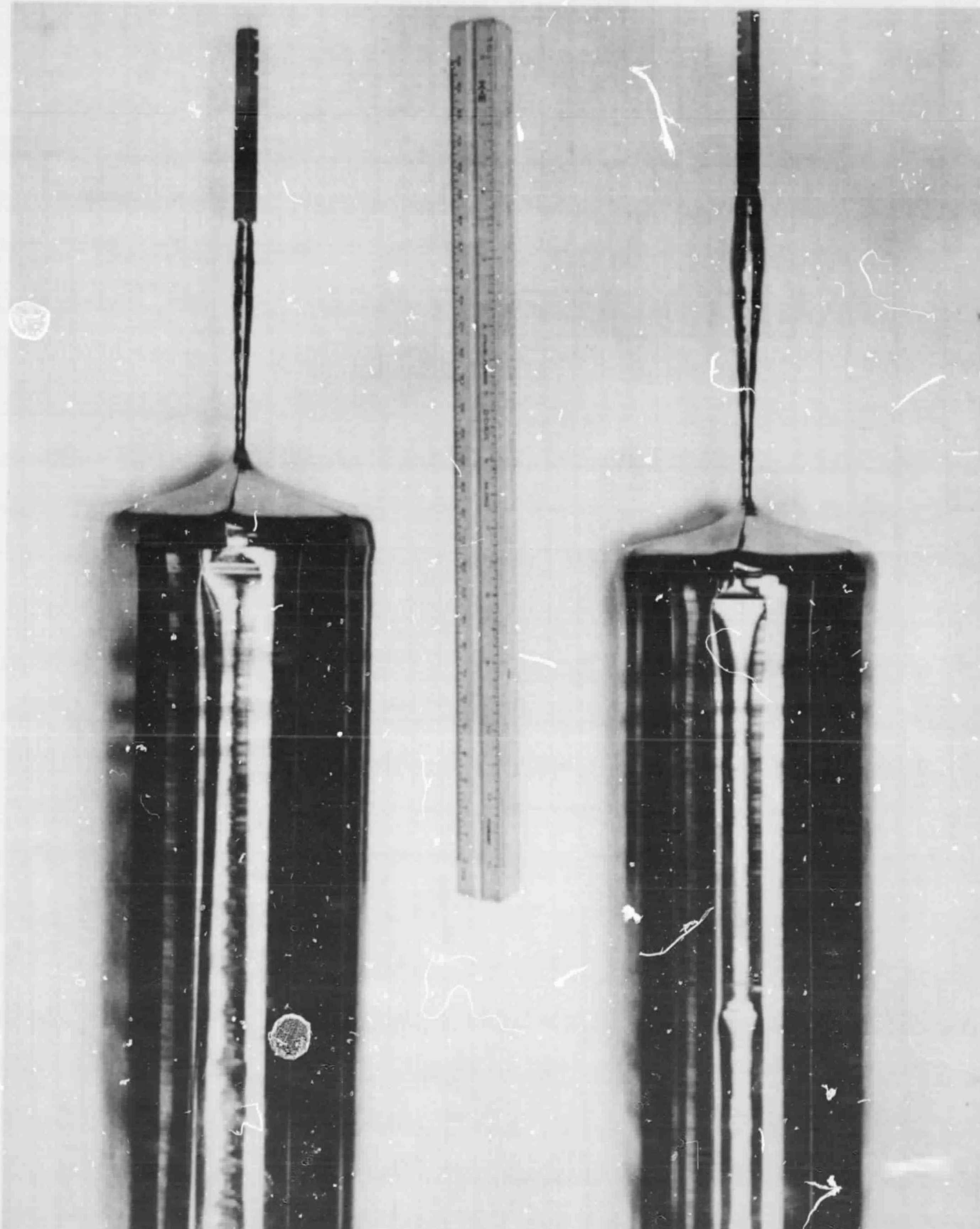

FIGURE 2
CRYSTALS GROWN WITH AGL COMPUTER/SENSOR SYSTEM

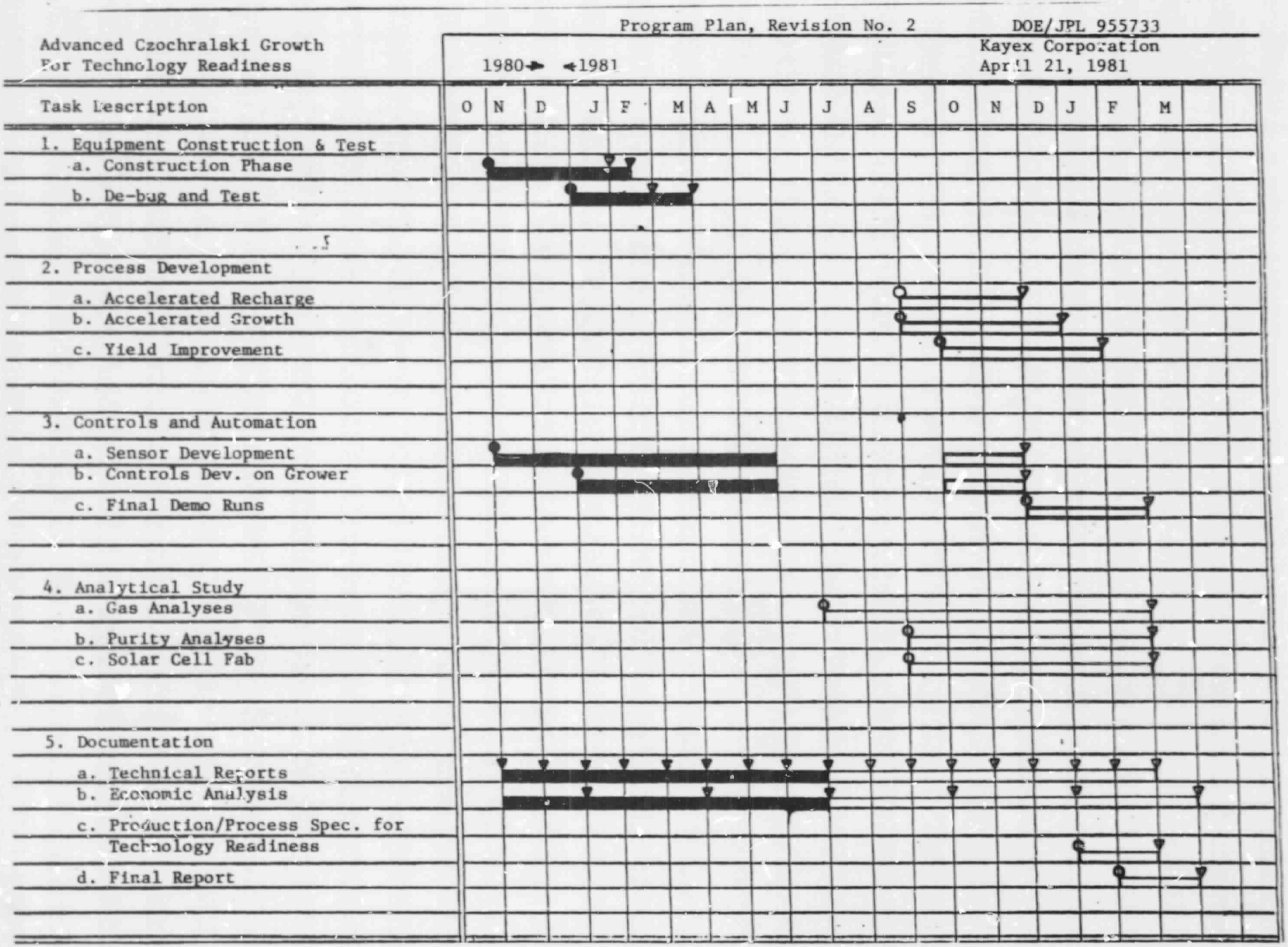

Figure 3

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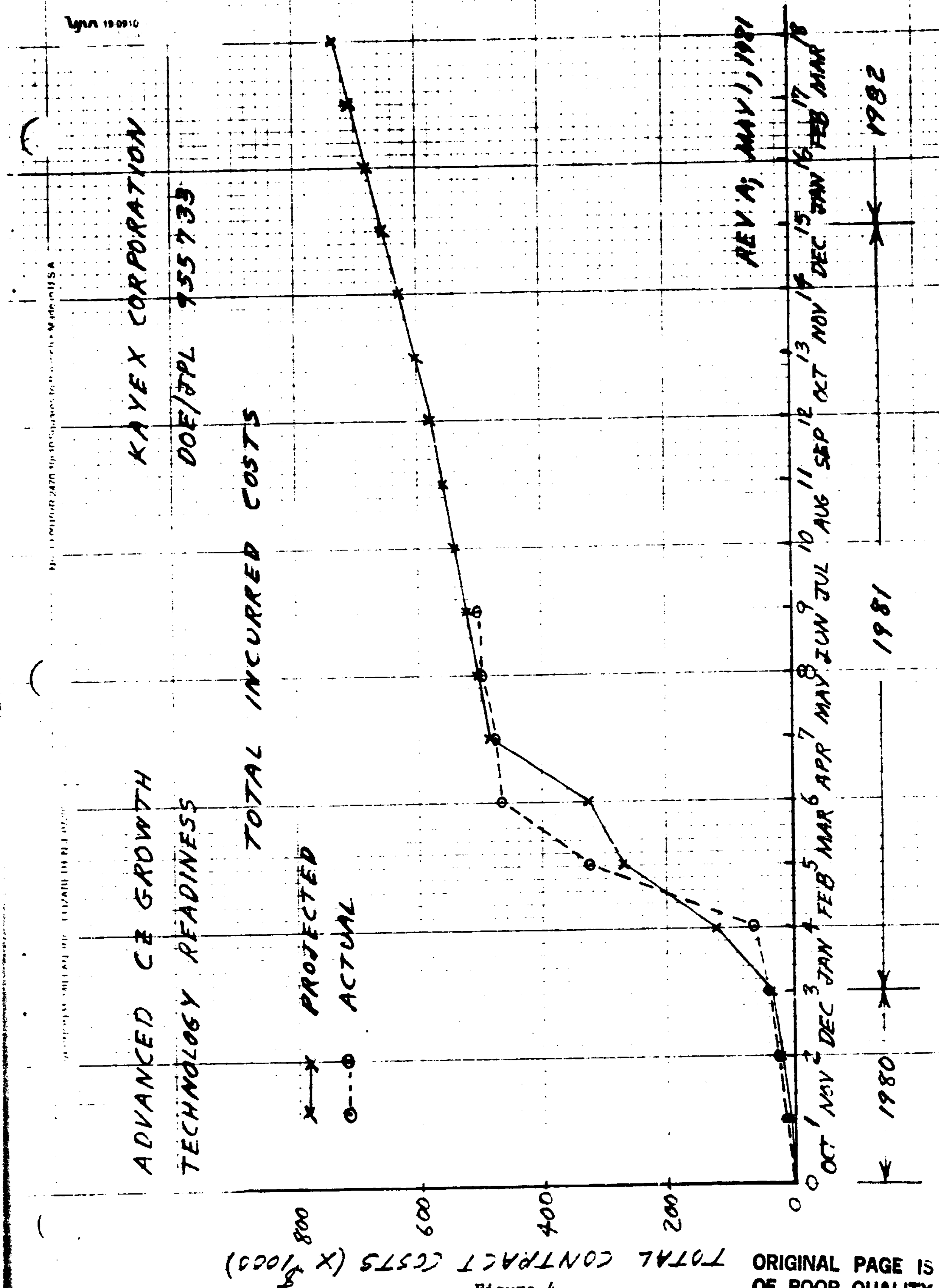
ADVANCED CZ GROWTH
TECHNOLOGY READINESS
TOTAL INCURRED COSTS
KAYEX CORPORATION
DOE/JPL 955733
REV A; MAY 1, 1981
PROJECTED
ACTUAL
TOTAL CONTRACT COSTS ($ X 1000)
0
200
400
600
800
0 OCT 1 NOV 2 DEC 3 JAN 4 FEB 5 MAR 6 APR 7 MAY 8 JUN 9 JUL 10 AUG 11 SEP 12 OCT 13 NOV 14 DEC 15 JAN 16 FEB 17 MAR 18
1980
1981
1982

Figure 4

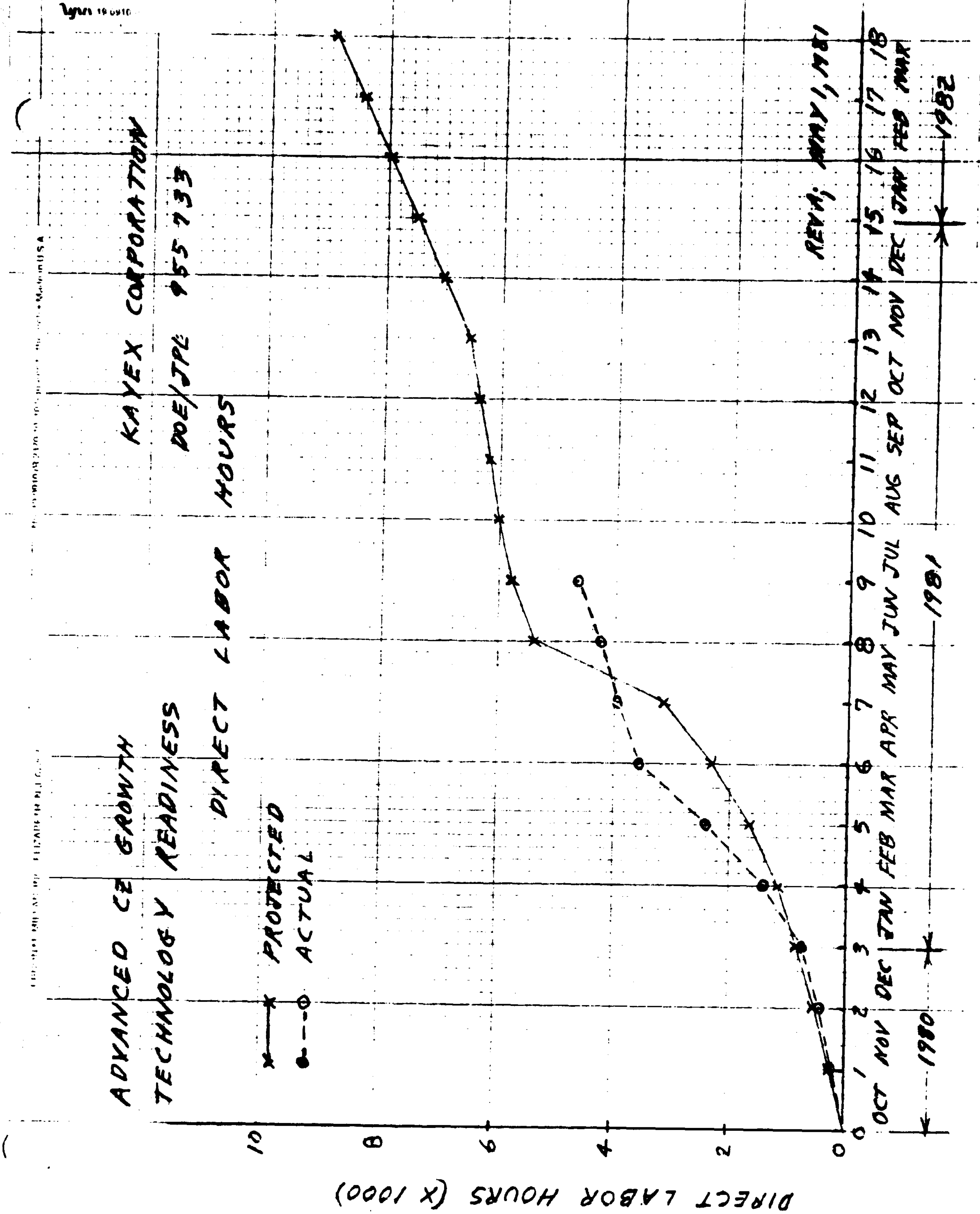

Figure 5

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